Proposal for Higgs and Superpartner Searches at the LHCb Experiment

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The spectrum of supersymmetric theories with R-parity violation are much more weakly constrained than that of supersymmetric theories with a stable neutralino. We investigate the signatures of supersymmetry at the LHCb experiment in the region of parameter space where the neutralino decay leaves a displaced vertex. We find sensitivity to squark production up to squark masses of order 1 TeV. We note that if the Higgs decays to neutralinos in this scenario, LHCb should see the lightest Higgs boson before ATLAS and CMS.

I. INTRODUCTION

Supersymmetry, and more specifically the minimal supersymmetric standard model (MSSM) [1] is a possible solution to the gauge-hierarchy problem and a favorite model governing physics above 100 GeV. Quantum corrections to the electroweak breaking scale are proportional to the superpartner masses, and thus one expects the MSSM spectrum to lie around the Z mass. Any significant deviation thereof necessitates a fine-tuning of parameters.

Minimal Supergravity (mSUGRA) is the most studied realization of the MSSM. It assigns universal masses to all scalars and to all gauginos at the scale 10^{16} GeV. Experimental bounds on the mSUGRA spectrum demand that the model is tuned to the per cent level [2]. Squarks and gluinos have lower bounds around 300-400 GeV [3], well above the Z mass. The corrections necessary to generate a Higgs mass consistent with direct LEP bounds [4] requires even more fine-tuning. The tight constraints on mSUGRA compel us to study more natural – *i.e.* less fine-tuned – models of supersymmetry.

The most general superpotential with the MSSM field content includes lepton and baryon number violating terms [5]

$$\lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \lambda''_{ijk} U_i^c D_j^c D_k^c, \quad (1)$$

where ijk are flavor indices. Bounds on proton decay severely constrain the combination of baryon and lepton number violation. Separately, however, they are much more weakly constrained. Throughout the following we restrict our attention to the baryon number violating operators, the λ'' terms. This choice is motivated by the interesting and challenging phenomenology it produces. The bounds for squark masses in this scenario are typically below 100 GeV [6]; some particles, such as the gluino and lightest sbottom, do not have published bounds above ~ 10 GeV in regions of parameter space [7]. Moreover, the bound on the Higgs can be below the Z mass when decays to neutralinos are kinematically allowed [8].

The phenomenologically interesting feature of this model is that the lightest superpartner - taken to be a neutralino - is unstable. It decays to three quarks. With regard to supersymmetry at the LHC, the signals are changed significantly – missing energy signals are largely absent, and the number of isolated leptons is reduced due to increased soft jet production [10]. The ATLAS and CMS experiments [9] will have weakened sensitivity to this scenario because their triggers are designed to exploit missing transverse energy and isolated leptons. In the case of squark or gluino production the associated jets should pass the triggers at ATLAS and CMS, however hard jets are typically pre-scaled by a large factor that would significantly reduce the effective luminosity [11]. Even if the trigger issue is solved, it is not clear that pure multi-jet events coming from this new physics can be seen above the (unknown) QCD background. Yet more worrisome is the Higgs decay. For decays to a final state of six soft jets, no obvious search strategy presents itself, while the standard searches are made more difficult with the reduced branching ratios.

The lightest neutralino has a macroscopic decay length in broad regions of parameter space. While neither ATLAS nor CMS currently employ a displaced vertex trigger, LHCb [12] is designed to trigger on and reconstruct such events. LHCb operates at a center of mass energy equal to that of ATLAS and CMS (14 TeV). However, its luminosity is limited to 2 fb^{-1} per year and it covers only the forward region. The experiment is designed to make measurements of rare b-hadron decays by relying on their ability to precisely reconstruct displaced vertices. The lower luminosity limits the average number of interactions per bunch crossing to $\lesssim 1$, which allows for more precise vertexing. This makes it an ideal experiment to search for our signal.

The purpose of this article is to show quantitatively that the LHCb experiment should have significant reach in the parameter space of this class of supersymmetric models. In parts of parameter space, it may be able to show the first direct evidence of the lightest neutralino and the lightest Higgs boson. Below we present our estimates of the LHCb's physics reach with regard to squark and Higgs production. Our work shows that the signal events easily pass the lowest level LHCb triggers. We suggest a modified high level trigger to increase the efficiency with which the signal is written to tape. While computational limits prohibit our complete understanding of the leading order QCD background, we argue that for some parts of parameter space the signal will dominate the background.

II. NEUTRALINO DECAY VIA BARYON NUMBER VIOLATION

The baryon number violating operators in Eq. (1) involve nine complex couplings (because j and k are antisymmetric). When the neutralino decays, it does so via the coupling λ''_{ijk} into up-type quark i and down-typed quarks j and k through an off-shell squark. A reasonable, theoretically motivated parameterization for these couplings based on a spurion analysis of flavor breaking in the standard model is [13]

$$\lambda''_{ijk} = \lambda''_0 \sqrt{\frac{m_i m_j m_k}{v^3 \sin\beta \cos^2\beta}}, \qquad (2)$$

where the m_i, etc., are quark masses [14], and $v\sin\beta$ and $v\cos\beta$ are the vacuum expectation values of the up-type and down-type Higgses respectively, with $v = 174$ GeV. We shall use this parameterization and take $\tan\beta = 1$ since any difference can be absorbed into λ_0. Note, the λ''_{323} coupling dominates. The dominant decay mode of the neutralino will be $\chi \to tbs$, unless the neutralino is lighter than the top in which case $\chi \to cbs$ dominates. In either case, neutralino decays are dominated by heavy flavors, and should contain additional displaced vertices. We will not utilize this additional handle on the signal, though it may prove to be a useful part of the full experimental analysis.

The strongest current bounds on the magnitude of λ'' couplings are from baryon number violating processes, namely neutron-antineutron oscillations and double nucleon decay in, for example, oxygen nuclei [15]. Such bounds allow $\lambda''_0 \sim \mathcal{O}(1)$ within QCD uncertainties. If the λ'' have arbitrary complex phases, they can contribute to direct CP violation in Kaon decays and to $K - \bar{K}$ mixing. The strongest bound in this case is the limit $\mathcal{I}(\lambda''_{313}\lambda''_{323}*) < 10^{-8}$ [16], which implies a bound on our universal parameter $\lambda''_0 \lesssim 1/20$ if all phase differences are order unity and squark masses are 100 GeV. There are no significant bounds on the individual λ''_{223} and λ''_{323} couplings. For a complete review, see [17].

The proper lifetime of the neutralino depends on the R-parity violating couplings, the neutralino mass m_χ, and the squark masses $m_{\tilde{q}}$. With the simplifying assumptions of a universal squark mass at low energies and a single dominant R-parity violating coupling (as in our parameterization), the proper lifetime is

$$\tau_\chi \simeq \frac{384\pi^2 \cos^2\theta_w}{\alpha |U_{21}|^2 \lambda''^2} \frac{m_{\tilde{q}}^4}{m_\chi^5} \qquad (3)$$

$$\sim \frac{3\mu m}{c |U_{21}|^2} \left(\frac{10^{-2}}{\lambda''}\right)^2 \left(\frac{m_{\tilde{q}}}{100\,\text{GeV}}\right)^4 \left(\frac{30\,\text{GeV}}{m_\chi}\right)^5.$$

where $|U_{21}|$ is an element of the neutralino rotation matrix (see [8]). We have neglected Yukawa couplings, QCD corrections and phase-space corrections (taking final state particles as massless). These are good approximations in the two cases we study. Yukawa couplings
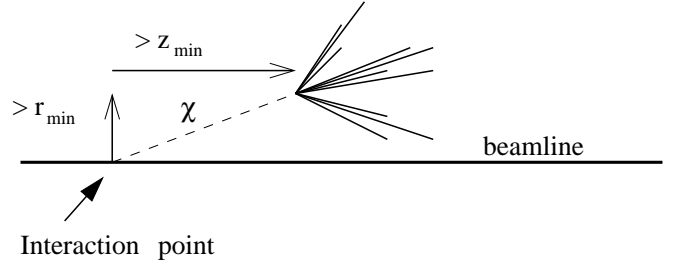

FIG. 1: A qualitative picture of a neutralino decay off the beamline. The decay is of a neutral particle (no track) into a large multiplicity of tracks. The invariant mass of the tracks should be significantly larger than those from a b-hadron decay. The quantities r_{min} and z_{min} are defined in the text.

are relevant to the extent that the lightest neutralino is partially higgsino. For Higgs production and decay, the neutralino is much lighter than the top, and for the decay to neutralinos to dominate, it turns out $\tan\beta$ should not be too large [8], and therefore all relevant Yukawa couplings are small. In the case of squark production, we will look only at the 'pure bino' limit (making the higgsinos and winos heavy), and thus we can ignore the Yukawas entirely. In the former case, $|U_{21}|$ is less than and of order unity. In the latter case (pure bino limit), $|U_{21}| = 1$.

III. SIGNALS AND BACKGROUNDS AT LHCB

Here we list the expected signals and backgrounds, proposed triggers and signal efficiencies, and offline discriminants:

- In Figure 1 we show pictorially a macroscopic decay of a neutralino off the beam line. The production signals we study are:

  - Squark production with $\tilde{q} \to q\chi_0$ and $\chi_0 \to qqq$.

  - Higgs production with $h \to \chi_0\chi_0$ and $\chi_0 \to qqq$.

  They are generated, including showering, with Pythia v6.400 [18]. For squark production we use the following parameters:

  - The ratio of couplings $(\lambda''_{223}/\lambda''_{323}) = (1/20)$.

  - A scan of $m_{\tilde{q}}$ from 100-1000 GeV in 100 GeV steps.

  - A scan of three different bino masses: $M_1 = 40, 100, 200$ GeV and three different coupling values $\lambda''_{223} = 10^{-3}, 10^{-4}$, and 10^{-5}.

  - $M_2 = M_3 = \mu = 1.2$ TeV while all other parameters are set to the Pythia default values.

For Higgs production we do the same scan of M_1 parameters and use $\tan\beta = 5$, $M_2 = 250$ GeV, $\mu = 120$ GeV, $m_{\tilde{q}} = A_t = 1$ TeV and $\lambda''_{223} = 10^{-2}$, with other soft terms at default values and other λ'' couplings set to zero.

- The background is taken to be multiple b production. We use Pythia to simulate $b\bar{b}$ events. Madgraph v4.1.19 [19] is used to compute matrix elements of $gb \to bb\bar{b}$, $gg \to b\bar{b}b\bar{b}$, and $gg \to b\bar{b}c\bar{c}$ while Pythia is used to shower these events.

- We find that the following cuts and triggers discriminate the signal and background:

    – Requiring a displaced vertex with 300 μm $< z < 0.4$ m and $r > 60$ μm, where z and r are the horizontal and perpendicular distance from the interaction point.

    – Requiring at least 5 tracks from the displaced vertex.

    – Requiring at least two tracks with $p_T \geq 1$ GeV and a two-dimensional impact parameter of 0.07 mm $< b_{IP} < 15.0$ mm

- For offline discrimination we use invariant mass distributions of displaced vertices.

We now describe the relevant aspects of the LHCb experiment [12] and explain in detail the motivation for and expected results of these cuts. LHCb is asymmetric in theta (polar angle) acceptance. The horizontal acceptance is 15 mrad $< \theta < 300$ mrad while the maximum vertical acceptance is 250 mrad. For simplicity we restrict our analysis to the region 15 mrad $< \theta < 250$ mrad. Offline reconstruction of the primary vertex is expected to have a resolution of $\lesssim 50$ μm along the beam line and $\lesssim 10$ μm perpendicular to it . The typical z resolution of a secondary vertex is ~ 200 μm. Transverse resolution is p_T dependent, and is ~ 20 μm for 1 GeV p_T track. We assume that vertexing may be done up to 0.4 m along the beamline which corresponds to half of the Vertex Locator length [20], We set the resolution of a displaced vertex to be a cylinder of 200 μm in z and 30 μm in r. This means that if a second vertex lies outside this cylinder then it can be distinguished, otherwise it cannot. We denote these lengths as δz and δr. The required minimum distances from the primary vertex as described above in z and r are denoted $z_{min} = 300$ μm and $r_{min} = 60$ μm. No detector effects beyond vertex resolution are considered.

A. Squark Production

All superpartners produced at the LHC cascade to the lightest neutralino (direct decays via R-parity violation are suppressed by the small λ'' coupling). For simplicity we look at squark pair production where each squark decays to a quark and the lightest neutralino. The goal
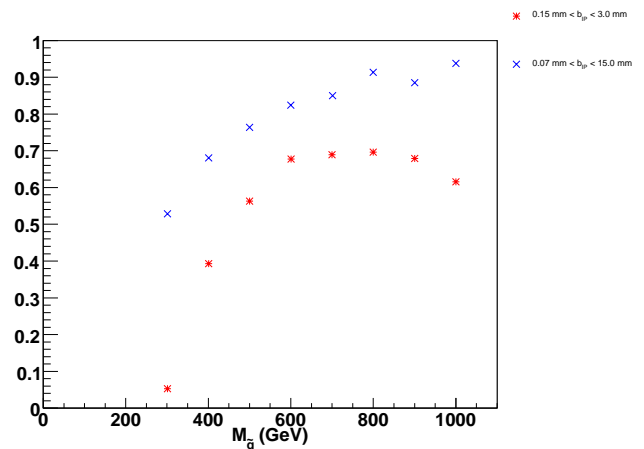

FIG. 2: Efficiency of χ_0 acceptance with respect to impact parameter requirements. We require 5 tracks, 2 of which with $p_T > 1$ GeV. The lower points show 0.15 mm $< b_{IP} < 3.0$ mm and the upper points show 0.07 mm $< b_{IP} < 15.0$ mm. The parameters are set at $\lambda''_{223} = 10^{-4}$, $M_1 = 200$ GeV, and $m_{\tilde{q}} = 400$ GeV.

of this search is to see one of these neutralinos in the LHCb acceptance. The signal we look for is a displaced vertex with a larger track multiplicity than a typical b decay and an invariant mass of the tracks larger than the b mass. The decay length may or may not be similar to a typical b hadron, so we do not use this as a distinguishing feature.

LHCb's Level 0 (L0) trigger is designed to reject multiple primary vertices ('pile up' events) and events with large numbers of tracks ('busy' events). L0 reduces the data rate from ~ 12 MHz to ~ 1 MHz. We find that 95% of our squark production signal (one neutralino leaving at least 5 tracks in the detector acceptance) passes L0. The High Level Triggers (HLT) are responsible for reducing the rate to 2 kHz, the read out rate. One component of the HLT is 2D track reconstruction searching for tracks with high p_T ($\gtrsim 1$ GeV) and large impact parameter, 0.15 mm $< b_{IP} < 3.0$ mm, tracks. Our signal generically produces more high p_T tracks than the background because of the neutralino's greater mass and because it is the product of a heavy particle decay. However, we find that the proposed impact parameter window results in signal efficiencies below 10% for decay lengths inconsistent with that of a b. The signal efficiency is increased to above 50% in most parts of parameter space if the impact parameter window is widened to 0.07 mm $< b_{IP} < 15.0$ mm. Figure 2 shows the efficiencies of the two ranges for a particular point in parameter space.

Extending the impact parameter range to a lower value of 50 μm is suggested in the context of LHCb upgrades [21]. The feasibility of extending the range to large values in unknown and requires a detector simulation. The naive background for large impact parameter tracks is
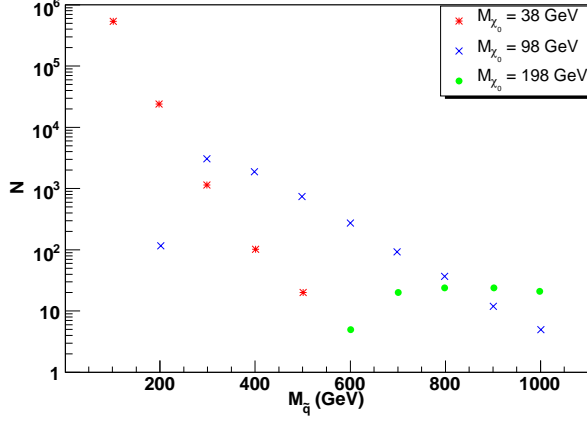
FIG. 3: Number of expected χ_0 events from squark production vs. squark mass. At least 5 tracks with 2 having more than 1 GeV of p_T and 0.07 mm $< b_{IP} <$ 15.0 mm are required. The coupling is $\lambda''_{223} = 10^{-4}$ and the neutralino masses are computed by Pythia using the parameters set at the beginning of the section.
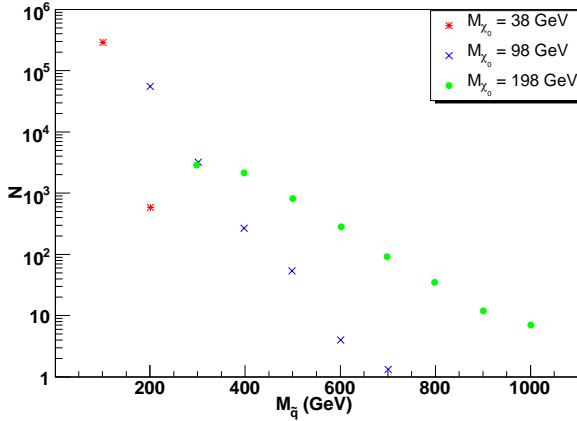
FIG. 5: χ_0 Invariant Mass from squark production. All points are $\lambda''_{223} = 10^{-5}$ with the same requirements as Figure 3. Red: $M_1 = 40$ GeV, $m_{\tilde{q}} = 100$ GeV. Blue: $M_1 = 100$ GeV, $m_{\tilde{q}} = 200$ GeV. Green: $M_1 = 200$ GeV, $m_{\tilde{q}} = 400$ GeV.

FIG. 4: The same as Fig 3 but with $\lambda''_{223} = 10^{-5}$

strange decays. This is because $\tau_{strange} c \sim$ centimeters. If this is the case, it seems plausible that requiring multiple tracks with high p_T can significantly reduce this background. Henceforth we optimistically assume that the range can be extended.

The expected event rate of neutralinos from squark production that pass our cuts are shown in Figures 3 and 4.

Figure 5 shows the signal invariant mass distributions of tracks for events that pass our cuts. As expected, these distributions reach far beyond the mass of a b-hadron, and thus we need not worry about isolated b decays as a background. We find rather that the most important background (offline) consists of b-hadron events in which
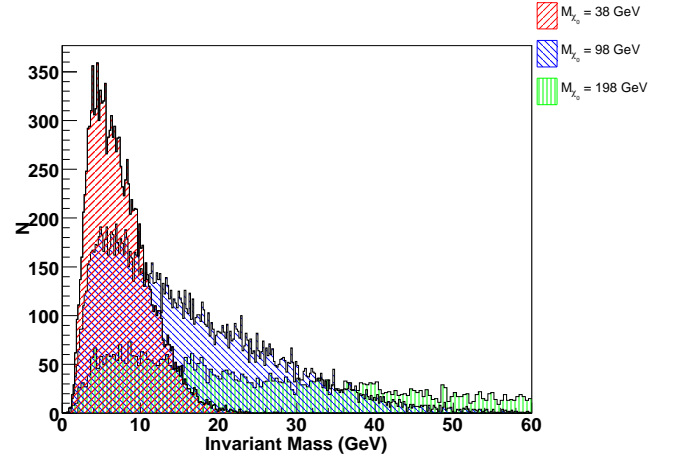
another particle, produced at the primary vertex, decays near enough to the b that the vertices cannot be resolved individually by the detector. We refer to these as overlapping events.

We now give a rough quantitative estimate of the background. Our region of interest is for track invariant masses above $2m_B \sim 12$ GeV. We see from Figure 5 this region has a significant overlap with our signal. Our limited computing power only allows us to simulate 10^{-5} years of background, in which we find no events which pass our track cuts and have an invariant mass above 12 GeV (see Figure 6). To better understand the background, we also look at the invariant mass of all decay products (charged and uncharged) from these overlapping events. Using this information, we are able to define cuts which should in principle reduce our background to less than 1000 events per year. Below, we describe how we come to this estimate.

The expression for the invariant mass of two particles is

$$M^2 = m_1^2 + m_2^2 + 2(E_1 E_2 - p_{z_1} p_{z_2} - p_{T_1} p_{T_2} cos\Delta\phi). \quad (4)$$

where m_i, E_i, p_{z_i}, and p_{T_i} are the mass, energy, z-momentum and transverse momentum respectively of the ith particle, and $\Delta\phi = \phi_1 - \phi_2$ is the difference in the azimuthal angle of the two particle momentum vectors. There are two overlap cases: $2b$s and a b plus a non-b. We discuss the $2b$ case. It is clear that the non-relativistic limit cannot produce $M^2 \gg (2m_b)^2$. The relativistic limit reduces (4) to

$$M^2 \simeq 2m_b^2 + 2p_{z_1}p_{z_2}\left(\frac{1 - c_1 c_2 - s_1 s_2 \cos\Delta\phi}{c_1 c_2}\right)$$
$$+ m_b^2\left(\frac{p_{z_1}c_2}{p_{z_2}c_1} + \frac{p_{z_2}c_1}{p_{z_1}c_2}\right) \quad (5)$$

where $c_i \equiv \cos\theta_i$, the cosine of the polar angle of the momentum vector of the ith particle, and similarly, $s_i \equiv \sin\theta_i$. (Note, the region of parameter space where one b is non-relativistic is a special case of what we discuss below).

Examining the cross term we see that there are two interesting cases: $p_{z_1} \sim p_{z_2}$ and $p_{z_i} \gg p_{z_j}$. The former case requires a large difference in polar or azimuthal angles to generate a large cross term. Maximizing this difference (for example, in the polar angle) while demanding a large cross term and using $p_T = p_z \tan\theta$ leads to a minimum p_T for the $b-$hadrons. Furthermore a large θ difference with a small transverse distance (making the vertices unresolved) requires the vertices to be as near the primary vertex as possible. These considerations significantly suppress the number of overlapping events. As an illustration we take $\delta r = 30\mu m$, the closer b a transverse distance of 30 μm from the z axis, and the vertices a distance of 360 μm from the primary vertex along the z direction. Demanding the cross term give 16 m_b^2 (to get an invariant mass of all decay products, not just tracks, of just over 20 GeV) we find that $p_z \gtrsim 160$ GeV. This corresponds to $p_T \gtrsim 20$ GeV for the softer b, a requirement which suppresses the cross section by better than 10^{-5} and makes this parameter range irrelevant.

Conversely, the case in which $p_{z_i} \gg p_{z_j}$ is important even when the θ difference is small. The non-relativistic corrections – the last term in Eq. (5) – dominate when the difference in angles vanish. Generating a cross term of $16m_b^2$ requires a ratio of 16:1 between the p_z's. The softer b (call it b_1) decays dominantly at a length $L \lesssim (p_{z_1}/m_b)\tau_b c$. Now the harder b has $p_{T_2} \simeq p_{z_2}\theta \simeq 16p_{z_1}\theta$. Using the requirement that $\theta \geq \frac{r_{min}}{L_1}$ (so the displaced vertex satisfies our r_{min} cut), and plugging the values of r_{min} and $\tau_b c$ leads to the requirement $p_{T_2} \gtrsim 2m_b$. To estimate our background, we create a sample of 10^{-5} years of $2b$ production using Pythia (roughly 10^7 events at leading order) requiring both bs to decay within the acceptance of our detector and to pass our r_{min} and z_{min} requirements. We then count the number of events that satisfy $(p_{z_2}/p_{z_1}) \geq 16$ and $p_{T_2} \geq 10$ GeV. The fraction of our sample which passes these cuts is one part in 2×10^3. Then we take the same sample without the momentum requirements and find the number of overlap events to be 69 – or scaled up, roughly 7×10^6 per year. If we take the distribution of momenta among these events to be flat (overly conservative), we can simply take a product of the two suppressions and estimate the number of events which have the potential to have a large enough invariant mass. Our estimate is $N < 7 \times 10^6 \times 5 \times 10^{-4} = 3,500$. If we include the fact that b's with very different momenta will have very different decay lengths, we find another suppression of a factor of nearly an order of magnitude and thus expect a background to be at most on the order of hundreds of events.

In addition to the $b\bar{b}$ background, there are overlap events generated in, for example, the $3b$ background. We find no events where two bs overlap giving a large invari-
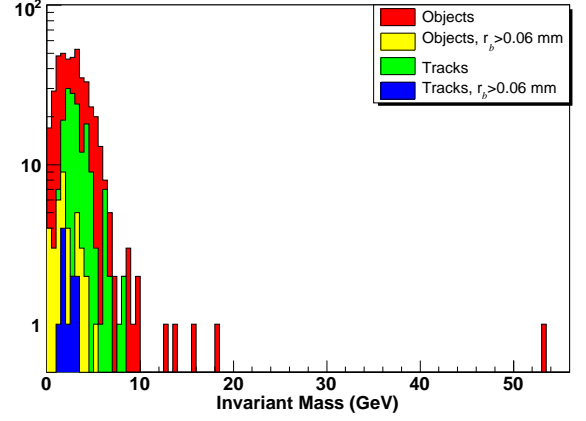

FIG. 6: Background invariant mass of overlapping events in $2b$ and $3b$ production. Objects are defined as all decay products that deposit energy in the detector (*i.e.* everything but ν's). We demand more than 5 objects or more than 5 tracks from a vertex. No cuts are made on impact parameter nor track/object p_T. All large mass events in red are due to b decay overlapping with a non$-b$ decay.

ant mass, and using similar arguments to those above find that a full year should produce at most as many events as in the $2b$ sample. However, we do find large invariant mass events in this sample which involve the overlap of a b and a strange hadron decay. These events do not pass either the 5 track cut or the r_{min} requirement. Imposing both should in principle severely limit or eliminate events of this type, but unfortunately it is difficult to estimate. We will simply assume they can be removed by these or similar cuts. In Figure 6 we plot the invariant mass of overlapping vertices in the $3b$ sample. We include in the plot the invariant mass of all decay products to see the large invariant mass events. All of the events with invariant masses larger than 10 GeV are due to b-non-b overlapping events.

The other simulated backgrounds produce an overlapping event fraction about that of $b\bar{b}$, and they are cross section suppressed by more than an order of magnitude.

We now estimate the parameter space that can be explored by LHCb. We assume a background of 400 events above 12 GeV of track invariant mass. Significance at the level of $\frac{S}{\sqrt{B}} > 5$ requires $\gtrsim 100$ signal events above 12 GeV. The regions of parameter space which exceed this event rate after cuts are:

- $\lambda''_{223} = 10^{-3}$:

  - $M_{\chi_0} = 38$: 200 GeV $\lesssim m_{\tilde{q}} \lesssim 600$ GeV.

- $\lambda''_{223} = 10^{-4}$:

  - $M_{\chi_0} = 38$: 100 GeV $\lesssim m_{\tilde{q}} \lesssim 400$ GeV.
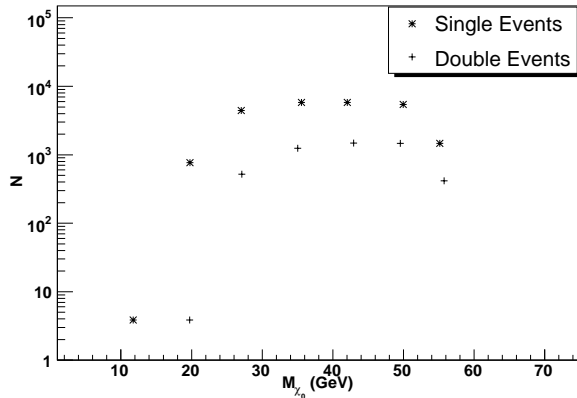 - $M_{\chi_0} = 98$: 200 GeV $\lesssim m_{\tilde{q}} \lesssim 700$ GeV.

FIG. 7: Number of Expected χ_0 in the acceptance from Higgs production and decay at 2 fb^{-1}. We require 5 tracks, 2 of which with more than 1 GeV of p_T and $0.07 < b_{IP} < 15.0$ mm. This point is $\tan\beta = 5$, $M_2 = 250$ GeV, $\mu = 120$ GeV, $m_{\tilde{q}} = A_t = 1$ TeV, and all other parameters at Pythia default values. The mass of the Higgs at this point is $m_h \sim 115$ GeV.

- $\lambda''_{223} = 10^{-5}$:
  - $M_{\chi_0} = 38$: 100 GeV $\lesssim m_{\tilde{q}} \lesssim$ 200 GeV.
  - $M_{\chi_0} = 98$: 200 GeV $\lesssim m_{\tilde{q}} \lesssim$ 400 GeV.
  - $M_{\chi_0} = 198$: 300 GeV $\lesssim m_{\tilde{q}} \lesssim$ 700 GeV.

B. Higgs Production

There exists an interesting region of parameter space in which the Higgs dominantly decays to neutralinos. The signal invariant mass distribution becomes more background-like in this parameter space as m_{χ_0} becomes lighter. In fact the distribution is almost indistinguishable from the overlap background in Figure 6 for $m_{\chi_0} \lesssim$ 20 GeV, in part because the neutralino vertex loses some of its track invariant mass through its decay to a b whose decay products often reconstruct at a different point.

However, a distinguishing characteristic of the signal is the possibility of both neutralinos being in the acceptance. An exemplary point is shown in Figure 7 where we use the leading order inclusive Higgs production cross section of $\sigma_h = 20$ pb [22]. We see that at this point if $m_{\chi_0} \gtrsim 25$ GeV then there are a significant number of Higgs decays that deposit both neutralinos in the detector. The expected background for this signal is two sets of overlapping decays which should be negligiable.

The rapid fall off of the acceptance distribution at small m_{χ_0} is primarily due to long decay length at these particular points. The decay length of a 20 GeV neutralino for the prescribed parameters is $L \sim 0.2$ m. Given that such a neutralino is boosted by at least a factor 3 due to the Higgs decay, we would not expect both neutralinos to be in the acceptance (defined with an upper z limit of 0.4 m) whereas it is not surprising that one of the decays is in the detector. Reducing m_{χ_0} by a factor of 2 leads to 32 fold increase, plus a significant phase-space increase of L – hence the sparseness of accepted events at small m_{χ_0}.

IV. DISCUSSION

The addition of baryon number violating operators to the MSSM superpotential allows for a more natural model of supersymmetry while also producing phenomenology that may pose difficulties for ATLAS and CMS. The central phenomenological signature is displaced vertices for which the LHCb is well suited to observe and reconstruct. Displaced vertices of $b-$hadron decays is a potentially enormous background. Despite computational limitation that forbid a full simulation of the background we can argue that it is plausible for large portions of parameter space to be explored. This is a consequence of the large invariant mass distribution of our signal, that necessitates coincident background decays. Thus we estimate that LHCb could rule out a significant portion of parameter space. However, only the most naïve detector issues have been considered and a full detector simulation is needed to understand the detector's true reach.

In addition to R-parity violating supersymmetry, other versions of supersymmetry may also contain displaced vertices. This includes parts of parameter space with near degeneracies between the LSP and NLSP which could occur between, for example, a stau and a neutralino, or between neutralinos in theories with an added singlet field. Finally, so-called 'hidden valley' models [23] also give rise to non-standard displaced vertices and have been suggested as good candidates for LHCb physics. A dedicated search at LHCb may provide the first discovery of new physics at the LHC.

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and
lxmon02.cern.ch/twiki/bin/view/Atlas/JetTiggerTable .

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[14] In principle, a top-down theoretical model for these couplings would associate their values to quark masses at high scales and then run the couplings down to the neutralino mass. Practically speaking, one should using the running quark masses at the neutralino mass (or roughly the weak scale) which results in order unity differences from their current masses. Pythia [18], which does implement this parameterization for R-parity violating couplings as an option, unfortunately uses the constituent quark masses for the light quarks, which has nothing to do with the flavor breaking. This option in Pythia should not be used.

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